Flowsheet Options For Processing Copper Gold & Gold Copper Ores

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ABSTRACT
Copper and gold have similar cyanide metallurgy depending on the nature of the minerals present. The processing of gold copper and copper gold ores can be highly problematic, site specific and the process selection is dependent on ore grade, mineralogy, acid leach behaviour, cyanide chemistry, product saleability and environmental considerations. The production of a copper gold concentrate is also an option where the copper is of a marketable grade.

In some situations the flotation tailings may be subject to cyanide leaching if technically and commercially viable. The general effects of copper on cyanide leaching chemistry are increased cyanide and lime consumption and decreased dissolution rates for gold and silver. The severe fouling of carbon, high solution losses and even re-precipitation of gold can occur.

Recent advances in cyanide recovery and producing saleable copper products have changed the flowsheets available for such problematic ores. There are a number of technologies and new methods now available.

INTRODUCTION
The technical and economic challenges of processing copper gold and gold copper ores remains a significant issue for the mineral processing industry. Copper and gold have very similar metallurgy making it difficult to separate them. This paper attempts to provide an overview of the various options and rationalize the process route based on fundamental concepts of ore grade, mineralogy and relating them to process objectives given the size of the resource and environmental considerations. The processing of gold-copper ores (higher values of gold than copper) typically follows the route of cyanidation, whereas for copper-gold ores (higher copper than gold values) the process route is typically flotation and smelting. In the latter case, gold credits are obtained from smelting the copper concentrates and if gold reports to the flotation tailings, they may also require cyanidation which can prove problematic with cyanide soluble copper.

MINERALOGY
Gold occurs typically as metallic gold, sometimes as electrum and can also occur in pyrite and arsenopyrite. It is not normally encapsulated in copper minerals. The main ore mineral of copper is chalcopyrite (CuFeS₂). Bornite (Cu₅FeS₄), covellite (CuS) and chalcocite (Cu₂S) are important sources in the world, and many ore bodies also contain some malachite (CuCO₃.Cu(OH)₂), azurite (Cu₃(CO₃)₂.Cu(OH)₂), cuprite (Cu₂O), tenorite (CuO) and native copper. The sulphides, which yield most of the copper produced throughout the world, generally occupy the deeper parts of lodes which have not been exposed to weathering. Near the surface they are altered by oxidation and other chemical actions to the native metal, oxides and carbonates. These secondary copper minerals may form rich
ore in the upper parts of many deposits, and, owing to their characteristic green or blue colour, even small amounts are easily seen in the rocks in which they occur.

**FUNDAMENTAL CONSIDERATIONS**

There are two fundamental considerations for the grade of copper and gold and the mineralogical composition. These are:

1. **Gold copper ores**—these are ores where gold is predominant and copper occurs as a secondary economic mineral.
2. **Copper gold ores**—these are ores where copper is predominant and gold occurs as a secondary economic mineral.

The key qualifying ore characteristics are:
- Are the copper minerals oxides, silicates, sulphides or a mixture?
- How soluble are the copper minerals in acid (especially sulphuric acid) and cyanide solubility?
- How amenable are the copper minerals to upgrade by flotation or gravity?
- What percentage of gold is soluble in cyanide solution?

**PRIMARY PROCESS OPTIONS**

There are five unit operations which must be considered. These are:

1. Pre concentration by gravity and flotation with concentrate sales.
2. Oxidation of sulphides and arsenides in whole ore.
3. Leaching of whole ore, concentrates or oxide material.
4. Leaching of tailings from the pre concentration process.
5. Smelting.

**PROCESS SELECTION ALTERNATIVES**

Typically the process selection depends on the following criteria:

1. Operating cost
2. Capital cost (CAPEX)
3. Simplicity of the process
4. Established technology
5. Safety
6. Technical Risk
7. Operability
8. Environmental issues

**CYANIDE SOLUBLE COPPER ISSUES**

The processing of copper gold ores presents significant challenges to metallurgists because both copper and gold have similar cyanide chemistry. The general effects of copper on cyanide leaching chemistry are increased cyanide and lime consumption and decreased dissolution rates for gold and silver. The challenges involved in the cyanidation of gold copper ores relates to their cyanide leaching and adsorption behaviour on carbon as summarised below. The problems with copper loading on carbon are not new.
High Cyanide Consumption
For every mole of copper that goes into solution, three or four moles of cyanide are required and unless steps are taken to do so, this results in increased cyanide losses. The cyanide consumption will increase directly in proportion to the cyanide soluble copper level in the ore. This can be established with a simple cyanide bottle roll test and reporting the percentage of cyanide soluble copper and the copper head grade. If the cyanide soluble copper level is higher than 100 ppm of copper then issues need to be taken to mitigate the copper.

High Weak Acid Dissociable (WAD)
The increased cyanide levels will result in stable copper cyanide complexes remaining in the tailings dam and in the return water. The copper will continue to leach in the tailings dam and the return water will build up in both copper and cyanide levels. At some operations this results in not pumping the tails return water to minimise the impact of the copper loading on the carbon. Another serious disadvantage is that whereas free cyanide levels normally decay by 50% every 24 hours, in this situation the copper cyanide levels will not break down, resulting in a potentially undesirable environmental problem and risk to wildlife (North Parkes). The WAD cyanide could be present in the dam for a very long time. The Cu(CN)\(^2\) complex adsorbs onto carbon causing severe carbon fouling whereas Cu(CN)\(^3\) is less of a problem. Inco Destruction (DETOX) processes using sulphur dioxide and copper as a catalyst will destroy free cyanide and WAD cyanide making it safe to deposit in tailings dams.

Difficulties Determining Free Cyanide
When copper goes into solution the normal silver nitrate rhodanin indicator titration method becomes erroneous because the copper cyanide complexes partially report as free cyanide. Some operators carry out copper solution analysis and then ensure the total cyanide is three to four times the copper level in order to ensure all of the cyanide complexes are present as Cu(CN)\(^3\) or Cu(CN)\(^4\) complexes.

Preg Robbing
If short term high grade slugs of copper ore are in the feed, then the copper will form CuCN and precipitate gold cyanide from solution, resulting in high tails. This was confirmed at Gabanintha where samples of tailings solids could be washed with cyanide solution reducing the gold level in the tailings solids.

\[
\begin{align*}
\text{Cu(OH)}^2 + \text{Au(CN)}^2 + e & > \text{AuCNCuCN } +2(\text{OH})_2 \\
\text{Auk} + \text{CuCN} + e & > \text{Au } +\text{Cu(CN)}^2
\end{align*}
\]

Staged addition of cyanide through the leach is necessary to prevent this happening. Excess cyanide at the front of the circuit will prevent this happening.

Adsorption Carbon Fouling Issues
The copper 2+ species (insufficient cyanide) will foul carbon very badly by loading onto the carbon at loadings up to 100,000 ppm and sometimes higher. The gold has to compete for active sites and usually low loadings are a result. This is why the bars from Chariot without doing anything could be as low as 10% gold, 85% copper and 5% other. This will also result in increased solution losses to tails (0.1 ppm Au compared to 0.01ppm). We also found increasing the pH>10.5 reduced copper adsorption onto the carbon.
High Oxygen Demand
The presence of copper sulphides in the ore reacting with cyanide requires oxygen similar to gold, according to Elnser's equation. If the ore has 7 ppm Au and 460 ppm copper then it is not hard to see the effect on the oxygen demand. Oxygen sparging will assist, however if the oxygen level drops then the leach kinetics will be affected. The single leach at bench scale will not pick up the full impact of cyanide soluble copper which loads onto the carbon and is concentrated in the tailings dam and returned to the plant via the tailings return water.

Number Of Adsorption Stages
Typical adsorption stage efficiencies are 50-60%. Where high grade feeds or solutions are treated the number of adsorption stages is consequentially higher. If the feed grade is 18 Au g/tonne the following would be expected. (assuming 50% stage efficiency). This can be modified by carbon concentration and carbon activity. Between eight and twelve stages will be required. This is very different to a typical Carbon In Pulp (CIP) plant. The carbon does not discriminate between a gram of carbon or a gram of copper and the total carbon and gold level will increase the number of stages and the carbon inventory. There are cyanide simulation models that can calculate this.

PROCESS SELECTION ELIMINATION
When dealing with processing a copper gold ore there are a number of processes that can be considered. In order to eliminate unlikely processes a table can be constructed of the likelihood of proceeding with a process route.

<table>
<thead>
<tr>
<th>Option</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Application</th>
<th>Consider</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentrate sales</td>
<td>No processing</td>
<td>Penalties for low grade, TC/RC costs</td>
<td>Common for copper grades &gt;25% Cu</td>
<td>YES</td>
</tr>
<tr>
<td>Roast Leach Electrowin</td>
<td>Recover copper and gold is high</td>
<td>Environmental issues sulphur dioxide. Must make sulphuric acid. High CAPEX</td>
<td>Used in the past not now</td>
<td>YES</td>
</tr>
<tr>
<td>CLEAR process</td>
<td>Copper and gold recovery</td>
<td>Materials of construction</td>
<td>Not used</td>
<td>NO</td>
</tr>
<tr>
<td>CYMET process</td>
<td>Copper and gold recovery</td>
<td>Materials of construction</td>
<td>Not used</td>
<td>NO</td>
</tr>
<tr>
<td>MINEMET process</td>
<td>Copper and gold recovery</td>
<td>Materials of construction</td>
<td>Not used</td>
<td>NO</td>
</tr>
<tr>
<td>ELKEM process</td>
<td>Copper and gold recovery</td>
<td>Materials of construction</td>
<td>Not used</td>
<td>NO</td>
</tr>
<tr>
<td>CUPREX process</td>
<td>Copper and gold recovery</td>
<td>Technical difficulties</td>
<td>Not used</td>
<td>NO</td>
</tr>
<tr>
<td>INTEC process</td>
<td>Copper and gold recovery</td>
<td>Materials of construction</td>
<td>Many ores piloted no operations</td>
<td>NO</td>
</tr>
<tr>
<td>BRISA process</td>
<td>Copper and gold recovery</td>
<td>Process not disclosed</td>
<td>Not used</td>
<td>NO</td>
</tr>
<tr>
<td>DEXTEC</td>
<td>Copper and Gold recovery</td>
<td>Materials of construction</td>
<td>Not used</td>
<td>NO</td>
</tr>
<tr>
<td>Outokumpu process</td>
<td>Copper and gold recovery</td>
<td>Materials of construction</td>
<td>Not used</td>
<td>NO</td>
</tr>
<tr>
<td>NSC process</td>
<td>Copper and gold recovery</td>
<td>Licenced technology no details</td>
<td>Piloted but no commercial plants</td>
<td>NO</td>
</tr>
<tr>
<td>Escondida ammonia leach</td>
<td>Copper and gold recovery</td>
<td>Technical issues</td>
<td>Not used</td>
<td>NO</td>
</tr>
<tr>
<td>Mt Gordon</td>
<td>Chacocite ore only</td>
<td>Limited application</td>
<td>Mt Gordon plant</td>
<td>NO</td>
</tr>
<tr>
<td>Process Name</td>
<td>Copper and gold recovery</td>
<td>CAPEX / OPEX</td>
<td>Operability / Costs</td>
<td>Commercial Status</td>
</tr>
<tr>
<td>----------------------------</td>
<td>--------------------------</td>
<td>--------------</td>
<td>---------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Pressure oxidation</td>
<td>high, established tech.</td>
<td>High CAPEX</td>
<td>Many plants</td>
<td>NO</td>
</tr>
<tr>
<td>Bioleaching</td>
<td>Copper recovery only</td>
<td>Chalcopyrite high; risky process</td>
<td>Not mainstream</td>
<td>NO</td>
</tr>
<tr>
<td>Resins</td>
<td>Copper and gold</td>
<td>Problematic</td>
<td>Not mainstream</td>
<td>NO</td>
</tr>
<tr>
<td>Geocoat</td>
<td>Copper and gold</td>
<td>Problematic</td>
<td>Not mainstream</td>
<td>NO</td>
</tr>
<tr>
<td>Activox</td>
<td>Copper only</td>
<td>Technical issues</td>
<td>Tati only</td>
<td>NO</td>
</tr>
<tr>
<td>Albion</td>
<td>Copper and gold, POX than POX, Low CAPEX than POX, Very flexible and low OPEX</td>
<td>Ultra fine grinding required. Arsenic stabilisation can be an issue</td>
<td>A number of plants operating</td>
<td>YES</td>
</tr>
<tr>
<td>AAC/UBC Process</td>
<td>Copper and gold</td>
<td>Lower CAPEX than POX</td>
<td>Pilot plant only</td>
<td>NO</td>
</tr>
<tr>
<td>Galvanox</td>
<td>Copper only</td>
<td>Operability issue</td>
<td>Pilot Plant only</td>
<td>NO</td>
</tr>
<tr>
<td>SART process</td>
<td>Copper from solutions, recover cyanide, Can recycle solutions.</td>
<td>Filtering the copper precipitate is a difficulty. Plants unnecessarily complex. Payback depends on grade.</td>
<td>Low uptake because of filtration of copper</td>
<td>YES</td>
</tr>
<tr>
<td>Glycine process</td>
<td>Copper and gold recovery High copper and gold recovery. Lower cyanide consumption. No environmental issues</td>
<td>Only at pilot stage. No engineering scale up data yet</td>
<td>Pilot but no operations yet</td>
<td>YES</td>
</tr>
<tr>
<td>Sceresenci process</td>
<td>Recover copper</td>
<td>Operability and costs were an issue. Not flexible. Not suitable high copper grades</td>
<td>Used at one plant</td>
<td>NO</td>
</tr>
<tr>
<td>AVR process</td>
<td>Recover cyanide</td>
<td>No copper recovery. High CAPEX</td>
<td>Used in NZ plant</td>
<td>NO</td>
</tr>
<tr>
<td>Membrane technology</td>
<td>Recover copper and cyanide</td>
<td>High risk, high CAPEX and OPEX</td>
<td>Not used</td>
<td>NO</td>
</tr>
<tr>
<td>Resins</td>
<td>Copper and cyanide</td>
<td>Operability, technical risks</td>
<td>Not used</td>
<td>NO</td>
</tr>
</tbody>
</table>

**CONCENTRATE SALES/SMELTING**

Selling concentrate for the life of the project is an option that often provides the highest financial outcome. The negative aspects are the expensive transport costs (approximately $US 90-150 per tonne) wet and the smelting treatment and refining costs (TC/RC). Gold credits can be as high as 100% payment. In addition penalties may be applied for arsenic, bismuth and other metals. Some contaminants such as mercury may limit the sale of the concentrate. The terms also stipulate delayed payment schedules. The copper smelting and refining industry is well developed and highly efficient. The traditional smelting route suffers some disadvantages for the concentrate producer. Firstly, the shipping of the concentrate from remote sites is expensive, secondly the treatment and refining charges (TC/RC) imposed by smelters fluctuates wildly over time. An example of the technology of this industry is Outokumpu’s Direct Blister Copper Process, which uses a flash smelting furnace to produce blister copper.
Copper concentrates were historically smelted; however, environmental issues are promoting the processing of concentrates by hydrometallurgical routes. Environmentally friendly >98% sulphur capture. Rule of thumb economic feasibility of a smelter is 150,000 tpa copper, although they do have a high turnover ratio and 40,000 tpa copper metal probably is the likely minimum for ISASmelt.

**ROAST LEACH ELECTROWINNING (RLE)**
The roast leach electrowin process (RLE) is very attractive because the roasting is autogenous and excess acid can be sold. The calcine is readily leached and using solvent extraction and electrowinning cathode copper can be produced with precious metals recovered from the residue.

- Low technical process; fine grinding not required;
- Leaching is operated at ambient conditions;
- Licence fees required for electrowinning; and
- Used in some Zambian operations.

**HYDROMETALLURGICAL PROCESSES**
Copper hydrometallurgy has been under active development for much of the last century. Key objectives are the recovery of precious metal values, fixation of iron suitable for disposal, conversion of the sulphur to a marketable product and fixation of impurities suitable for disposal. The media used for hydromet processing are chloride (or chloride/bromide), sulphate, mixed sulphate chloride and nitric acid or ammonia. Technical problems have impacted on the commercialization of these processes.

**CLEAR PROCESS**
The CLEAR process involved leaching in a mixed potassium/sodium chloride solution. The major problem was the rejection of impurities from the cathode product. The residue was used as fertilizer for banana crops.

**CYMET PROCESS**
This process was developed by Cyprus Metallurgical Services. The process was very similar to the CLEAR process with copper recovered as cuprous chloride crystals and converted to copper using hydrogen reduction. Problems were experienced with consistent copper quality.

**MINEMET RECHERCHE PROCESS**
In this process leaching is at 50 C using cuprous chloride solvent extraction and organic stripping using sulphuric acid. The process has been run at pilot scale.

**ELKEM PROCESS**
This process treats complex concentrates using a chloride brine solution. Copper is recovered by direct electrolysis, zinc by solvent extraction, lead by crystallization of lead chloride and iron is removed by oxyhydrolysis. The process is complex and has been piloted.

**CUPREX PROCESS**
In this process the concentrates are leached using ferric chloride. Iron is rejected as goethite and copper is recovered by solvent extraction and electrowinning. Technical issues have limited development of the process.

**INTEC PROCESS**

**Technology Overview**
The Intec Process is actually a suite of related technologies that use concentrated brine (chloride, bromide and iodide solutions) to leach metals into solution, then purify them to recover high-grade commodity products for sale on domestic and international markets.

**Leach Step**
Although the process is cyclic, the conceptual 'first' step is to add the mineral concentrate or industrial waste feedstock to the leach reactors. Depending on the specific application, most or all of the metals in the feedstock are dissolved into solution. Then, under the conditions in the leach, the iron and other unwanted elements are precipitated as a stable iron oxide-based solid residue that is suitable for disposal or reuse in other industry applications.

**Purification**
After separating the solid leach residue, the impure metal-bearing electrolyte is purified by selectively separating important but low-concentration elements such as gold, silver and indium. These are recovered as saleable by-products.

**Recovery**
Lastly, the purified electrolyte is then passed to the product recovery section, where the primary-value metals such as copper, lead, zinc and/or nickel can be recovered in various saleable forms. After recovering these products, the barren electrolyte is then cycled back to the leach step in a closed-loop circuit.

**BRISA**
The BRISA process is being developed by a Spanish research institute and currently still at laboratory scale. There is no large scale test work or industrial application available on this technology. The applicability of BRISA process for treating MMK concentrate cannot be verified. Therefore, the process cannot be considered further.

**DEXTEC**
The DEXTEC process was a patented process from the late 1970s. The process is a typical chloride leach and thickening operation similar to the Cymet process. There is no large scale plant or industrial application available for the DEXTEC process and it has not been seen in the technology market since a legal campaign with a European company. Therefore, due to the discontinued development of the process.

**OUTOKUMPU**
The Hydro Copper process developed by Outokumpu operates in a chloride environment allowing economical copper metal production.

**NSC PROCESS**
This process is based on moderate pressure oxidation at 125-155C, catalysed with nitrogen species supplied from sodium nitrite, preceded by an ultrafine grind to 10 microns.
Copper is recovered by conventional SX/EW. A small commercial circuit operated until the mid 1990’s at Sunshine Mining and Refining in Montana. Further development work is being undertaken by the Center for Advanced Mineral and Metallurgical Processing, Montana, USA, including the use of the existing Sunshine plant to treat a cobaltite and chalcopyrite concentrate for the Formation Capital Corporation Idaho Cobalt Project.

**ESCONDIDA AMMONIA LEACH**

This process was developed by BHP and employs air combined with a solution of ammonia and ammonium sulphate to leach cuprous salts from chalcocite solutions. Approximately half the copper is leached and the remainder can be recovered by a flotation recycle. Information is limited on the Escondida process; therefore it has been decided not to pursue the process any further. In addition, several attempts were made to contact the Escondida mine, as well as BHP’s base metal department. No responses were received, hence the lack of information available to consider the process further. Furthermore, the process does appear to be unattractive due to the ammonia used in the leaching process and the unnecessary complexity of the process.

**MT GORDON PROCESS**

This process is used at Western Metals’ Mt Gordon operation in Queensland, which produces about 50,000 tones/annum of high grade cathode copper from chalcocite ore by ferric leaching and low pressure oxidation. It incorporates a moderate feed grind of 75-106 microns, and copper recovery is by conventional SX/EW. Future plans include the treatment of chalcocite concentrates from lower grade ore, and the further development of the process to treat chalcopyrite concentrates.

**PRESSURE OXIDATION**

The world’s second largest copper producer Phelps Dodge are building a US$40 million pressure oxidation demonstration plant at Bagdad Arizona, which will treat about 136 tonnes/day of concentrate to produce just under 16,000 tonnes/annum of copper cathode via conventional SX/EW.

**BIOLEACHING**

The bioleaching of flotation concentrate is a new method for copper recovery that could form the basis of an economic and environmentally friendly process. The main objective is to use bioleaching process from the treatment of copper concentrates, using mesophilic bacteria. The most important operating parameters are copper dissolution (%) and surface area. A culture of Thiobacillus ferrooxidans was used for the bioleaching tests. Bioleaching has been problematic and is not yet mainstream technology. Recent advances have been made leaching chalcopyrite at higher temperatures and with the BHP patent using a copper chloride couple to achieve high recoveries.

**RESIN TECHNOLOGY**

The development of gold specific resins from Henkel has increased the options available for copper gold cyanide solutions. Similarly there are resins which are copper specific.

**GEOCOAT**

GeoBiotics of Lakewood Colorado taking an alternative approach to bio-leaching. Their GEOCOAT® process involves the coating of concentrates onto a suitable substrate, usually barren rock, then stacking the coated material in a conventional heap fashion. The heap is irrigated with acidic solutions containing iron and nutrients, while low
pressure ambient air is applied at the heap base. The technology was initially developed for gold, recovery, and an extensive program is being carried out for copper sulphides.

**ACTIVOX**

The process relies on fine grinding and low temperature leaching at 90 C. Solid liquid separation and solvent extraction electrowinning. This process has been taken off the market.

**ALBION PROCESS**

The Albion Process is a process used for the recovery of base and precious metals from refractory sulphide ores. The Albion Process incorporates ultrafine grinding to increase the activity of sulphide concentrates to a point where they can be oxidised readily in conventional open tanks, without the need for high pressures, expensive reagents or bacteria. The technology is simple, robust and offers substantial cost savings over bacterial or pressure leaching.

**AAC/UBC PROCESS**

Anglo American Corporation and the University of British Columbia are developing a medium pressure oxidation process operating at 150C, to which surfactant is added to disperse the molten sulphur. The feed is finely ground to 10-20 microns, and copper recovery is via conventional SX/EW. A pilot plant program is underway at the AARL facilities in South Africa.

**GALVANOX PROCESS**

GALVANOX™ is a set of methods for leaching copper from concentrates containing a mixture of copper sulphides, but particularly those containing chalcopyrite (CuFeS₂). It was developed by researchers from the University of British Columbia (UBC). This process allows complete copper leach recovery to occur with low grade concentrates. It takes advantage of the galvanic effect between chalcopyrite and pyrite. Chalcopyrite is a semiconductor, and therefore corrodes electrochemically in oxidizing solutions. In ferric sulphate media, the overall leaching reaction is as follows:

\[
\text{CuFeS}_2 (s) + 2 \text{Fe}^2(\text{SO}_4)^3 (a) \rightarrow \text{CuSO}_4 (a) + 5 \text{FeSO}_4 (a) + 2 \text{S0} (s)…..(3)
\]

This reaction may be represented as a combination of anodic and cathodic half-cell reactions:

Anode: \(\text{CuFeS}_2 \rightarrow \text{Cu}^{2+} + \text{Fe}^{2+} + 2 \text{S0} + 4 \text{e}^– \)…………………………..(4)

Cathode: \(4 \text{Fe}^{3+} + 4 \text{e}^– \rightarrow 4 \text{Fe}^{2+} \)………………………………………………(5)

**THE SART PROCESS**

The SART process has been designed to recycle cyanide and recovery copper from pregnant solutions containing gold. The name of the process makes reference to the unit operations of the process: Sulphidization, Acidification, Recycling of precipitates and Thickening of precipitates. Basically, the process starts with the precipitation of copper sulphide by adding sulphuric acid and sodium hydrosulphide at pH 5. The reactions of sulphidization and acidification promote the formation the HCN gas, which is kept in solution. The reactions of the process are shown below:
\[
2\text{CN}^- + \text{H}_2\text{SO}_4 = 2\text{HCN(ac)} + \text{SO}_4^{2-} \tag{6}
\]
\[
2\text{Cu(CN)}_2\text{Z}^2 - + \text{S}^{2-} + 6\text{H}^+ = \text{Cu}_2\text{S(s)} + 6\text{HCN(ac)} \tag{7}
\]

According to these reactions, the acidification of the solution allow to break the metallic compounds of weak cyanide formed by the reaction of cyanide with copper, zinc, nickel, silver and mercury. The addition of sodium hydrosulphide promotes the precipitation of metallic ions dissolved as metallic sulphides such as copper, which is present as copper sulphide. Basically, the efficiency of the copper precipitation is 82-92% and the precipitate contents 62-68% of copper. The solids formed during the precipitation process are removed by several stages of thickening, filtration and drying. The reactor feeds a thickener and the solid percent is increased from 1 % to 15%. In order to promote the precipitation and increase the size of the flocs precipitated, 85-90% of the thickener underflow is recycled to the precipitation stage. The other fraction is neutralized with sodium hydroxide until pH 12 to avoid the formation of HCN gas and goes to the filtration stage where the precipitate is dewatered. The final product is copper sulphide (Cu2S) and the moisture of the product is 8-10%.

The thickener overflow and the filtration solution are mixed and neutralized with lime until pH 11. In this case, the neutralization with lime produce the conversion of HCN to calcium cyanide and the precipitation of calcium sulphate (gypsum), which is separated by thickening and filtration. The reactions involved in this stage are shown below.

\[
2\text{HCN(ac)} + \text{Ca(OH)}_2 = \text{Ca(CN)}_2 + 2\text{H}_2\text{O} \tag{8}
\]

\[
\text{SO}_4^{2-} + \text{Ca(OH)}_2 = \text{CaSO}_4(\text{s}) + 2\text{OH}^- \tag{9}
\]

The gypsum thickener operates with recirculation of 85-90% of the underflow. The other fraction of the underflow is sent to filtration in order to recover the gold and cyanide contained in the filtration solution. The overflow of the gypsum thickener and the remaining of the filtration solution are the final solution of the SART process and are recycled to the leaching process with the remaining content of cyanide. An aspect very important of the process is the scrubbing system to absorb any eventual release of HCN gas or H2S. A solution of sodium hydroxide is added to the scrubber to neutralize acid gases.

SART has not been widely taken up because of operational issues mainly the issues of filtering finely precipitated copper sulphide. Also issues with gypsum scale have proven problematic.

**GLYCINE PROCESS**

The glycine leach process is a leaching process used for extraction of base metals including copper. Mining and Process Solutions (MPS) has acquired global, exclusive rights to commercialise GlyLeach. The challenge now is to identify the most promising applications, and to methodically lower the barriers to the first commercialisation event. This may well be a heap leach project, where GlyLeach offers a unique solution to several significant types of copper and gold ore deposits: - Copper oxide with high acid consumption - Copper oxide with leachable gold value - Copper ores with high clay content - Low grade copper sulphides - Gold ore with high cyanide consumption due to nuisance copper - Gold projects where the use of cyanide is prohibited

Recently Telfer copper concentrate has been piloted with glycine and cyanide “Glycat” leaching and achieved high gold recovery with significantly lower cyanide consumption
SPECIFIC PROJECT EXAMPLES
The following projects highlight the different approaches taken to project development where copper and gold occurred together.

Telfer-Newcrest-WA
Originally Telfer operated as a heap leach of gold ore containing copper resulting in problems with carbon fouling. They introduced the SART process until the heap leach closed. The reopened Telfer gold project floats a high grade copper concentrate which is shipped to smelters. Telfer also produces a low grade copper (2%) pyrite gold concentrate which is cyanide leached onsite and the residue copper disposed of. Cyanide consumption is very high. They have been testing glycine and cyanide leaching and this appears to achieve high gold recoveries with much lower cyanide consumption.

Boddington-WA
The feed grade is 0.8 g/t Au and 0.2% Cu. Flotation to produce a copper gold concentrate for sale and cyanide leaching of the tailings. There is a trade-off between copper recovery to concentrate and copper levels in CIL. The low grade copper concentrate (16%) is sold to smelters who want the high gold level and accept the low grade.

Mt Gibson-WA
The feed grade was 3 g/t Au and 0.1% Cu. Cyanide leaching of gold ore containing copper resulting in problems in the CIP plant with carbon fouling. Developed the Scerescini process to recover copper from the carbon and sell as copper sulphate.

North Parkes-NSW
Cyanide leaching of gold ore containing copper resulting in problems in the CIP plant with carbon fouling. Environmental issues with tailings dam impact on wildlife. High free cyanide levels required to achieve gold recovery.

TC8-NT
The feed grade was 8 g/t Au and 0.2% Cu. TC8 operation was a gravity and CIL gold plant from a magnetite ore. Cyanide leaching of gold ore containing copper resulting in problems in the CIP plant with carbon fouling due to cyanide soluble copper.

Mt Leyshon-QLD
Cyanide leaching of gold ore containing copper resulting in problems in the CIP plant with carbon fouling.

Red Dome-QLD
Originally a free milling oxide ore low in copper. At depth the cyanide leaching of gold ore containing copper resulting in problems in the CIP plant with carbon fouling.

Cadia-NSW
Underground copper gold ore from block caving. Used flotation to produce a copper gold concentrate for shipment and sale. Recover gold from the concentrate using Falcon concentrators.

Selwyn-QLD
The oxide ore was processed through a CIL gold plant. For the primary ore flotation to produce a copper gold concentrate for shipment and sale to smelters was used.

**Gabarintha-WA**
Initially very successful CIL leaching of oxide ore 3 g/t Au however the project failed processing transition and fresh primary ore 3 g/t Au 0.3% Cu. The high cyanide consumption and high solution loss with carbon fouling and progressively lower gold recovery. The plant was closed and the ore trucked to Meekatharra and diluted with oxide gold ore.

**Horse Shoe Lights-WA**
Operated in the nineteen eighties producing a flotation concentrate and cyanide leaching of the flotation tailings- eventually going broke. High cyanide consumption, carbon fouling and low gold recovery.

**North Pole-WA (Pilbara)**
Very high oxygen demand, which was not picked up with oxygen uptake rate test. Dore bars high in copper, solution losses high. Gold losses in slag high.

**Browns Creek-NSW**
The copper level was 0.4% and a combination of gravity plus flotation and CIP was used plus leaching of gravity concentrates using Aurix resins.

**Chariot Project Warrego,-NT**
The gold grade was 3 g/t Au and copper from 0.1 to 0.5% Cu. Blending of feed grade to control cyanide soluble copper. 50% gravity gold recovery. Had to manage the feed cyanide soluble gold ore. Carbon fouling and solution loss

**Yanacocha Heap Leach**
Newmont Mining operates the Yanacocha mine in Perú and the gold milling section of the property includes a Sulfidisation-Acidification-Recycle- Thickening (SART) plant to remove copper from pregnant leach solution. Since its commissioning in 2008, the plant has been intermittently operated as needed to remove copper upstream of a carbon adsorption circuit. However, starting in 2015 Newmont expects the plant to operate on a more continuous basis in response to higher copper ores that will be processed in the gold mill. A paper at a recent SME Annual Conference in Denver presented results from the campaign that demonstrated the SART plant is capable of efficiently treating high-copper leach solution. During the campaign, leach solution copper levels ranged from about 100 to 700 mg/litre, and copper removals ranging from about 56% to +99% were achieved. The median copper removal efficiency observed during the campaign was about 94%. The primary plant modification determined necessary following the campaign was the need to improve consistency with sulphide dosing.

**CONCLUSIONS**
Copper and gold have similar metallurgy and chemistry, so the economic processing of copper gold and gold copper ores will always provide technical challenges to Metallurgists. Specific key tests are initially required to determine the grade, mineralogical composition and leach extraction efficiency in cyanide and acid. The development of new oxidative processes to treat sulphides offers economic advantages over traditional processing
techniques. Traditional smelting routes are losing favour because of environmental issues and a trend to processing on site to maximize revenue and save on shipping and TC/RC costs. Also the ability to process complex sulphides is a significant advantage. For ores containing significant cyanide soluble copper, a number of new developments show promise for copper and gold separations and cyanide recovery. The development of specific resins for copper and gold are specifically significant. The past decade has seen more developments in copper gold technology than the previous 100 years. It is anticipated there will be further developments in this area and commercialization of some of this new technology.

SART is applicable for high cyanide soluble copper ores but filtration of the fine copper sulphide still presents a challenge. The use of glycine and glycine cyanide mixes shows promise to be attractive and better than glycine alone for copper ores.

ACKNOWLEDGEMENTS

The author would like to thank various companies, all colleagues, engineers at various sites, METS staff and other consultants for their contribution and the management of METS for their permission to publish this paper and constructive criticism of various drafts.

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